TPC Simulation Road Map

GAS SIMULATOR

HITS (dedx)

E Gen

ELECTRONS

Diff

Distort

PHITS

READOUT SIMULATOR

Amplif

Pad Resp

Pulse Gen

DIGITS

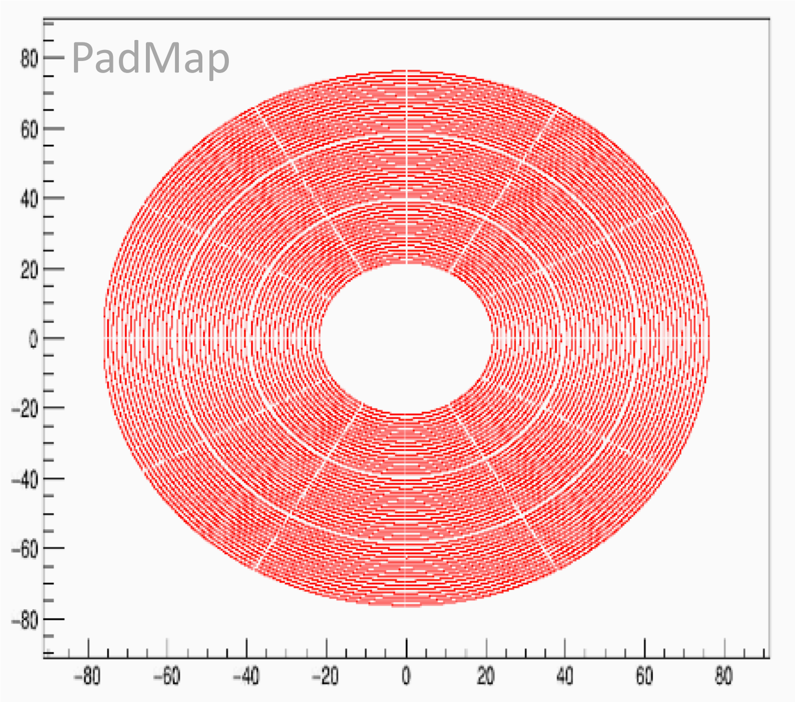
RAW READER

TRACKER

TRACKS

RECONSTRUCTOR

CLUSTERS



base/TPCParameters
base/TPCPadMap
sim/PHG4TPCDetector
reco/TPCClusterer

ADDITIONAL MATERIAL

Status of TPC Simulation as tracking and particle identification detector

Carlos Perez

TPC simulation in a nutshell

1. Simulation of ionization energy loss in gas
u2. Simulation of free electron production
u3. Transport of electrons/ions in E and B fields
4. Pad response in capturing electrons
5. Electron avalanche in GEM
6. Time development of signal
7. Digitization
u8. Clusterization

u: recently updated and under testing under branch repository named SBUTPC

Contents

- Broad discussion of current tracking and my suggestions for update

TPC simulation update

- Elements of the TPC simulation
- Adaptation into sPHENIX

The strength(=weakness) of the current tracking approach

- It was made VERY generic.
  - All detectors => 3D points in “cartesian coordinates”
- Pro:
  - Useful for testing different detector technologies at unison.
  - Provides a simplified environment where we can quickly add leading effects as parametrizations.
- Con:
  - Very SLOW
  - Very entangled

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The current code can be easily made faster now that we have defined the geometry of MAPS, INTT and TPC by using the symmetries that the detectors have.

E.g. Currently we clusterize in TPC profiting from cylindrical symmetry, however we then transform those clusters into cartesian coordinates (using very expensive trigonometric functions) only to convert them back to another coordinate system later during tracking (again trigonometric conversions) besides transforming their respective covariance matrices.

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For a longer term solution one has to really reorganise the software. E.g. to make use of virtual classes for clusters that allow construction of different standards for MAPS, INTT and TPC.

Why Kalman-filter could be a good idea for sPHENIX?

- Pro:
  - It does simultaneously pattern recognition and track fitting
  - Handles multiple scattering and energy loss very well. Factorizes-out point-to-point correlation due to MS, thus avoiding inversion of large matrices.
  - Provides a natural way to extrapolate out to other detectors (TPC - INTT - MAPS - INTT - TPC - CALORIMETERS)
  - Handle on cluster grooming on the spot.
  - Has been used successfully by similar tracking concepts: STAR and ALICE
- Con:
  - Relies heavily on seed

BRIEF UPDATE ON TPC SIMULATION

TPC simulation in a nutshell

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Geant4 has a very good description of this step (PAI model)

TPC simulation in a nutshell

1. Simulation of ionization energy loss in gas Geant4
2. Simulation of free electron production

Sampled from Poisson(Nt)

Nt is computed from dEdX in gas (~28 pr e/cm for Ar at MI)

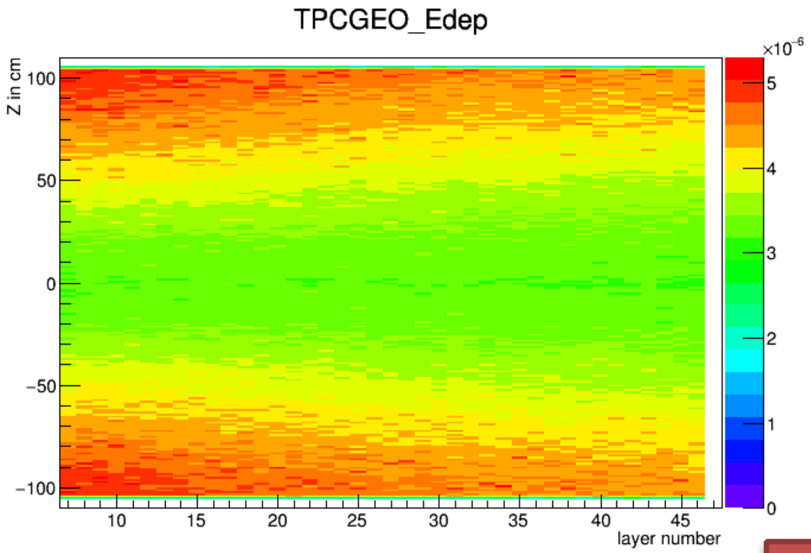
=========

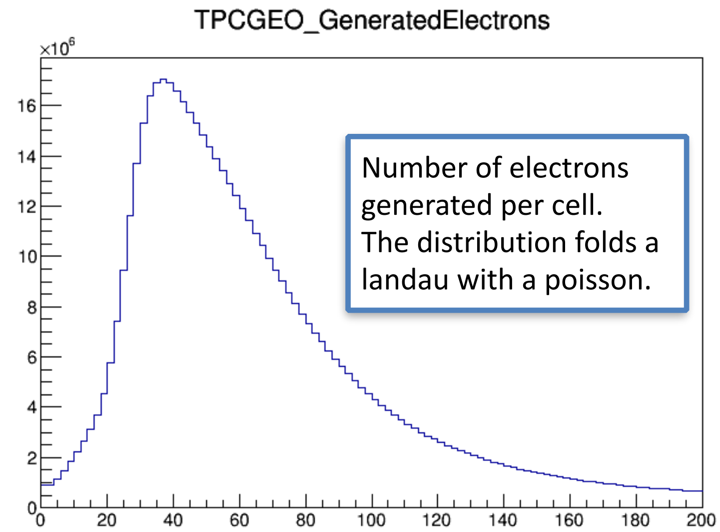
Kinetic energy of primary electron sampled from dNdE(E) distribution

Average no of secondary electrons is parametrized following n0 = (E-I)/W/(1-F)

Total Number of electrons per primary: N = 1+Bin(n0,1-F)

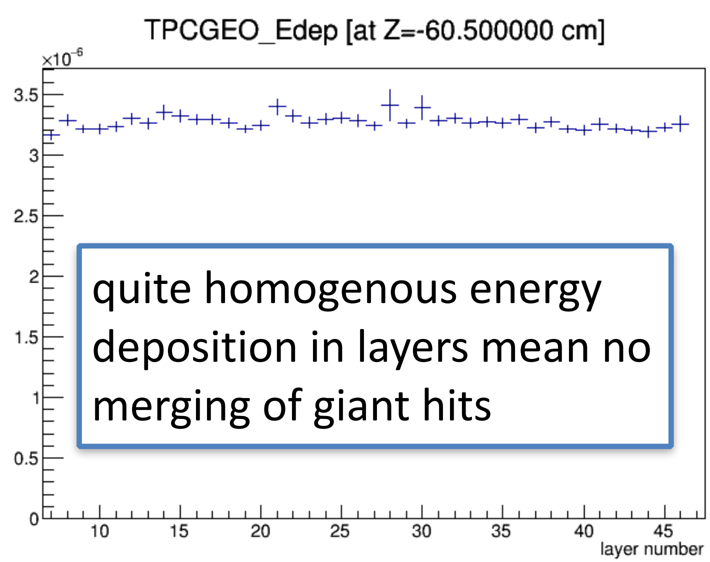
NeCF4-94-6 free electron production



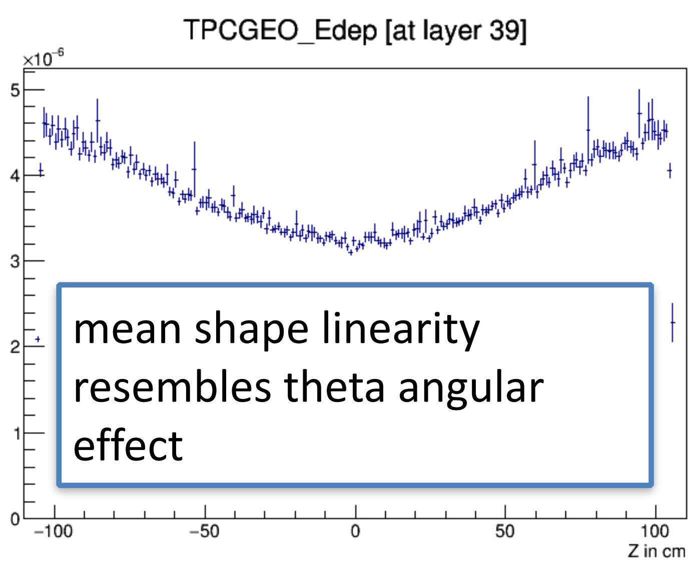


Number of electrons generated per cell.
The distribution folds a landau with a poisson.

Hijing central



quite homogenous energy deposition in layers mean no merging of giant hits



mean shape linearity resembles theta angular effect

TPC simulation in a nutshell

1. Simulation of ionization energy loss in gas Geant4
2. Simulation of free electron production parametrization
3. Transport of electrons/ions in E and B fields

Two folded:

1) Diffusion due to E and B
   sigmaTransverse = DiffCoeffT(B) x Sqrt[drift_length]
   similar for Longitudinal

2) SpaceCharge distortions
   due to ions (mainly back-flow from GEMs)
   LUT implemented from independent simulation

TPC simulation in a nutshell

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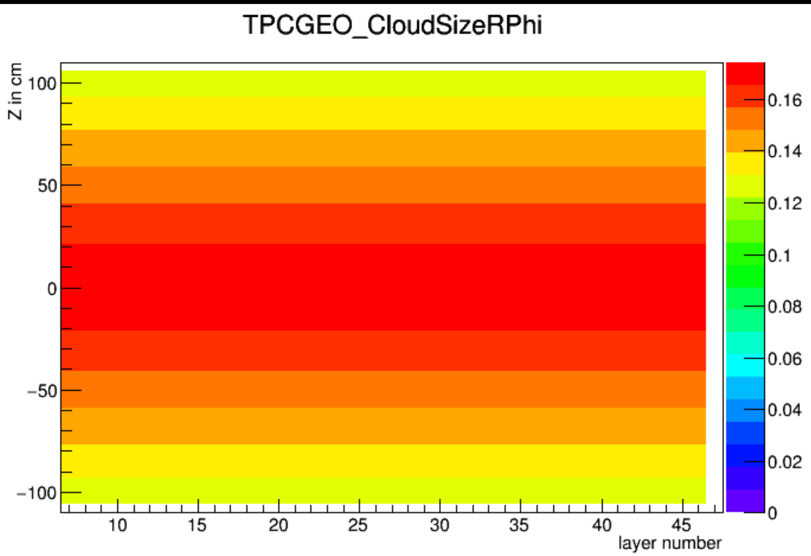
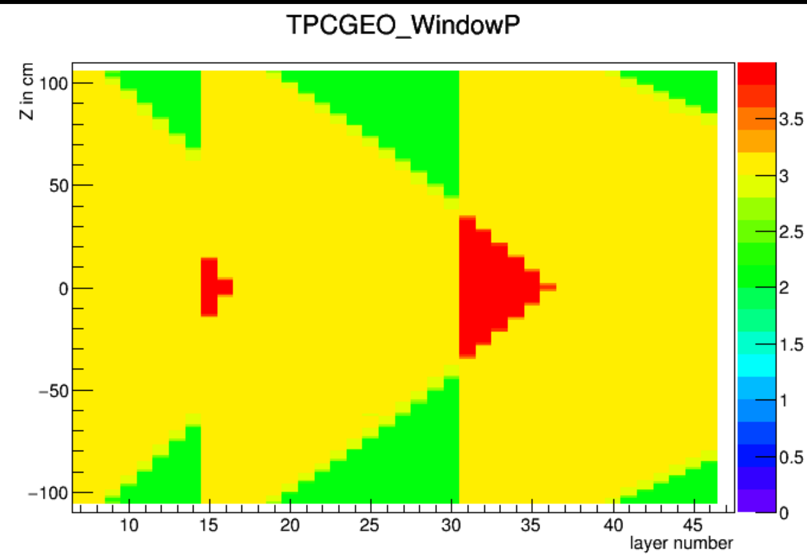
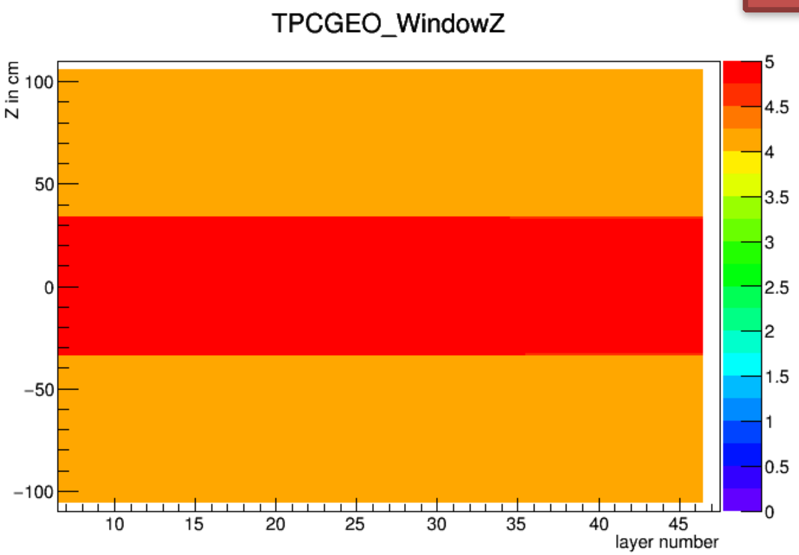
Currently all these red steps are folded into effective intrinsic GEM resolution

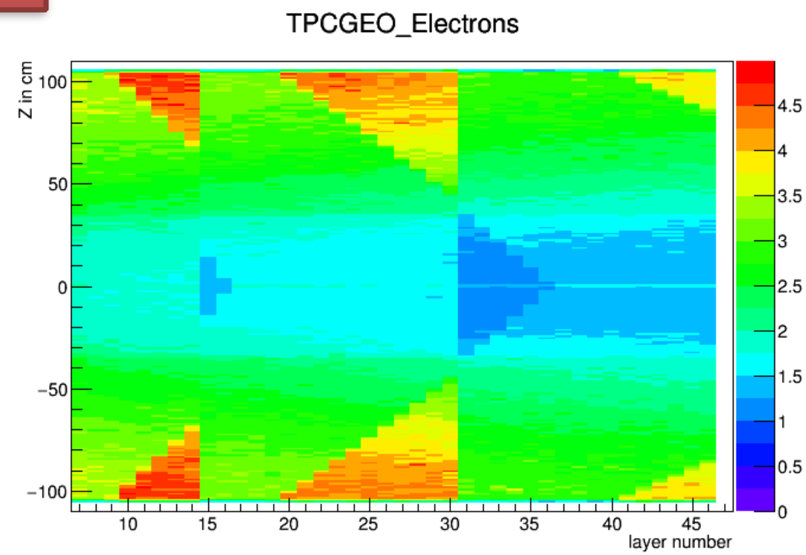
Free electron following toward endplate



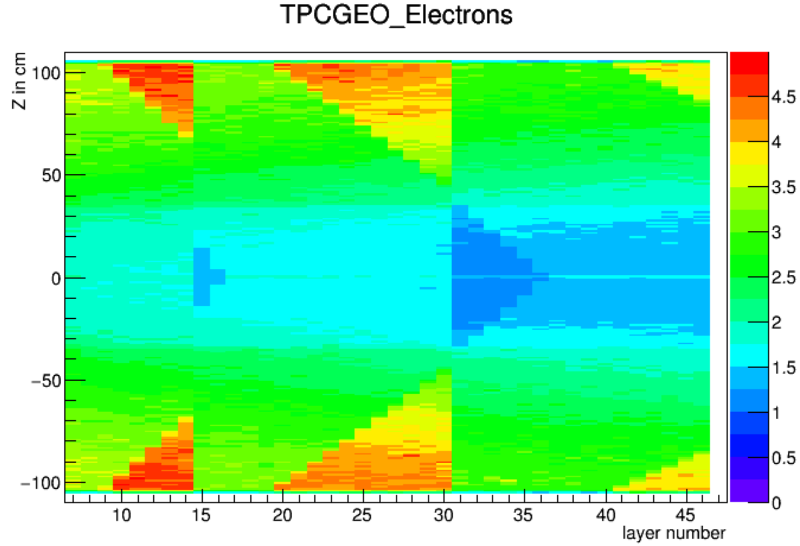


Hijing central

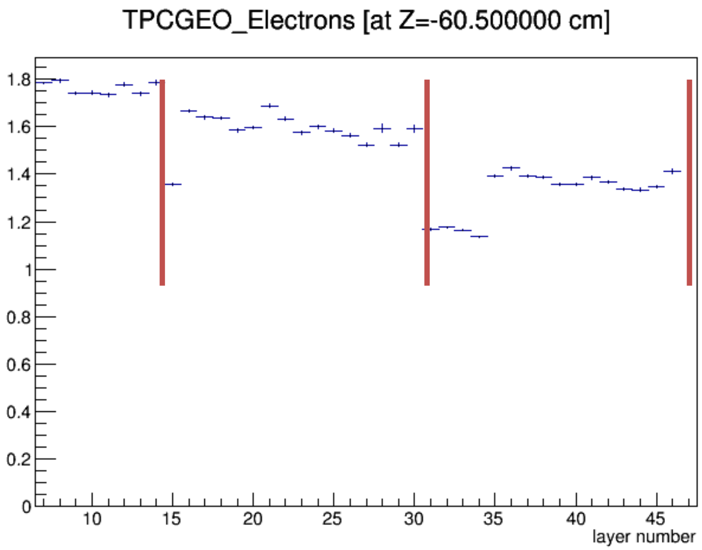


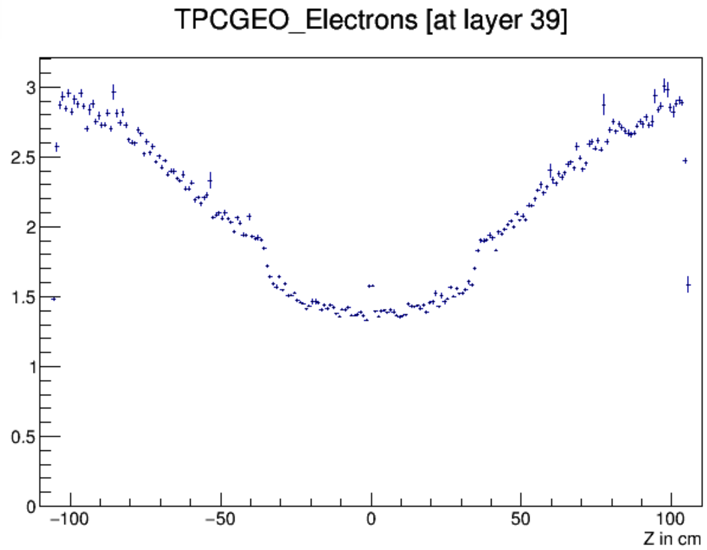


Free electron following toward endplate



Hijing central





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8. Clusterization

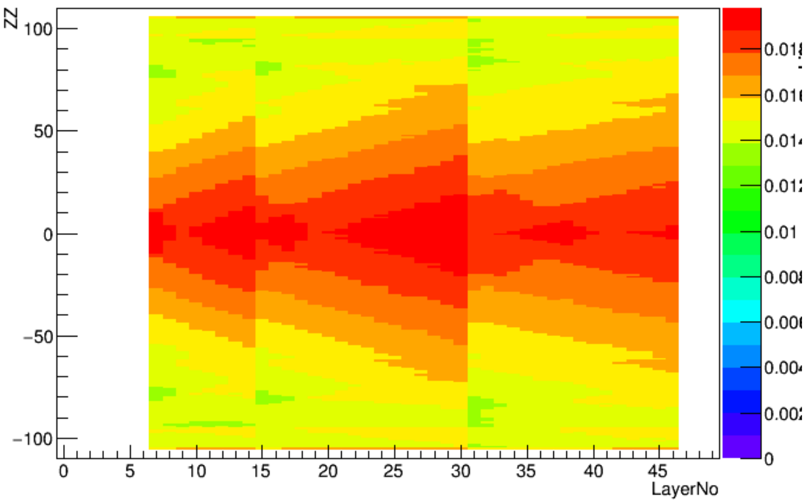
Clusterization

- After signal is digitalized, we scan the rphi-z cells and find local maxima in a neighbourhood whose width varies according to Z position.
- Once a local maximum is found the surrounding cells are used -assuming a 2D-gaussian profile- to compute mean and variances. During this procedure we reject signal smaller that a constant fraction threshold currently set at 5% that it is accessible from macros.
- Variances are used for error computation of the mean and cluster size.
- Values are transformed to XYZ coordinate system and pushed to hit3D for pattern recognition.

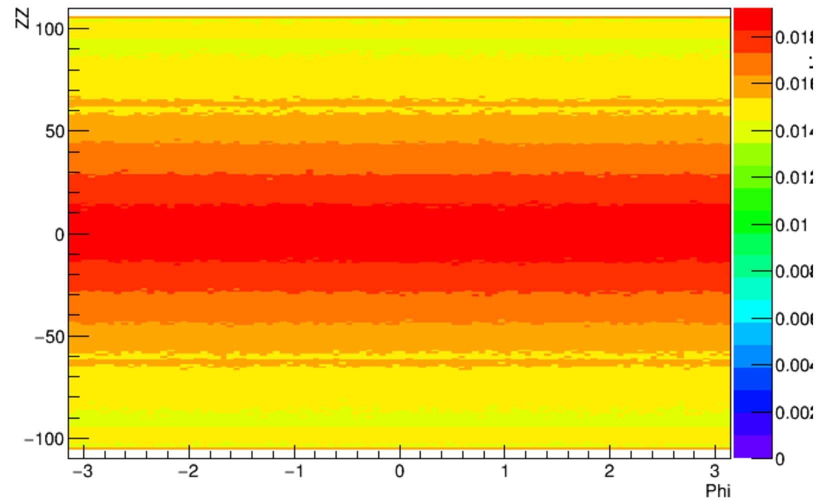
todo: current algorithm does not separate share sharing

Clusterization

CLUSTER_ErrorPP

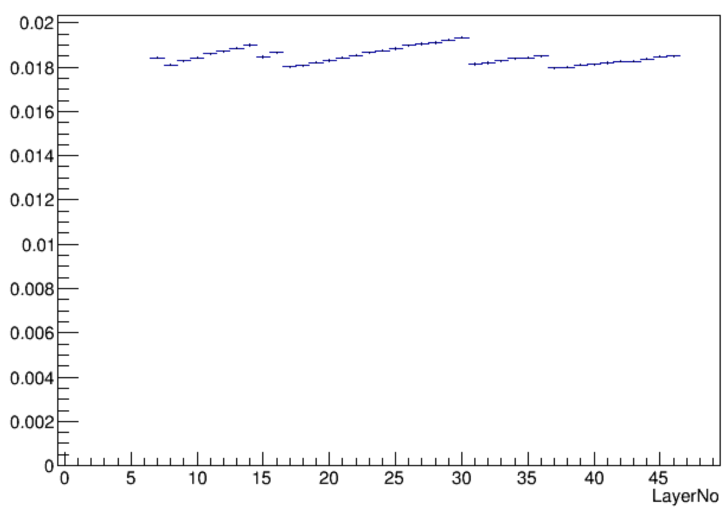


CLUSTER_ErrorPP2

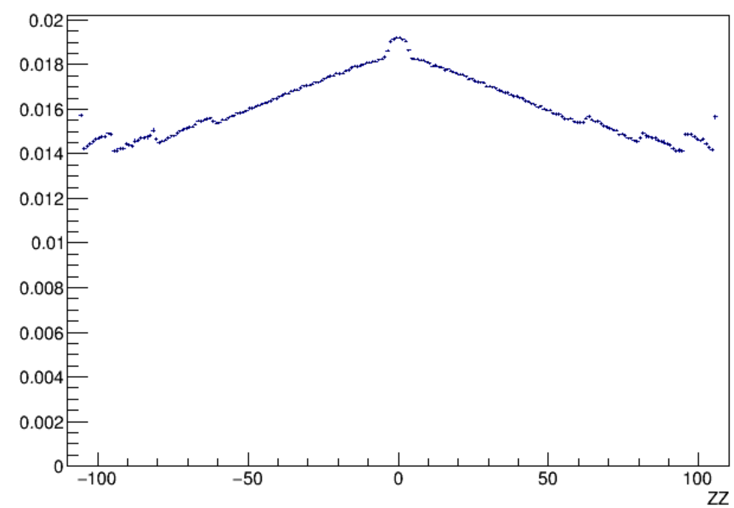


Hijing central

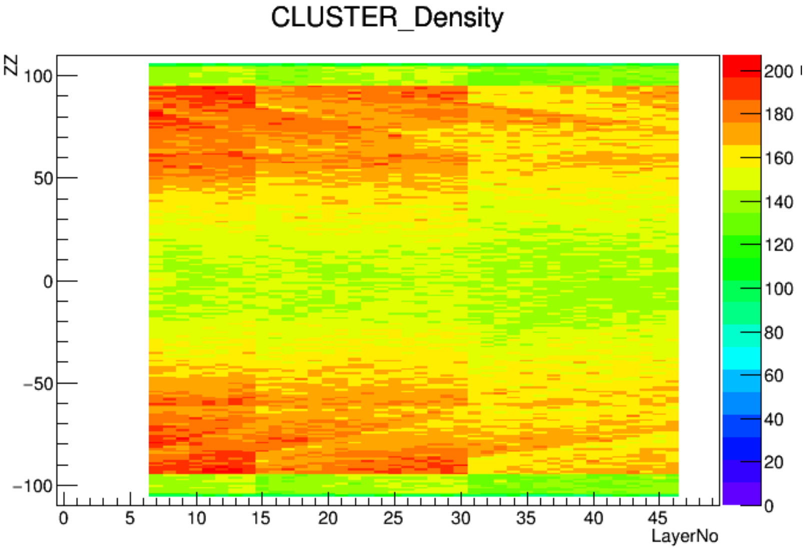
CLUSTER_ErrorPP [at Z=-60.500000 cm]

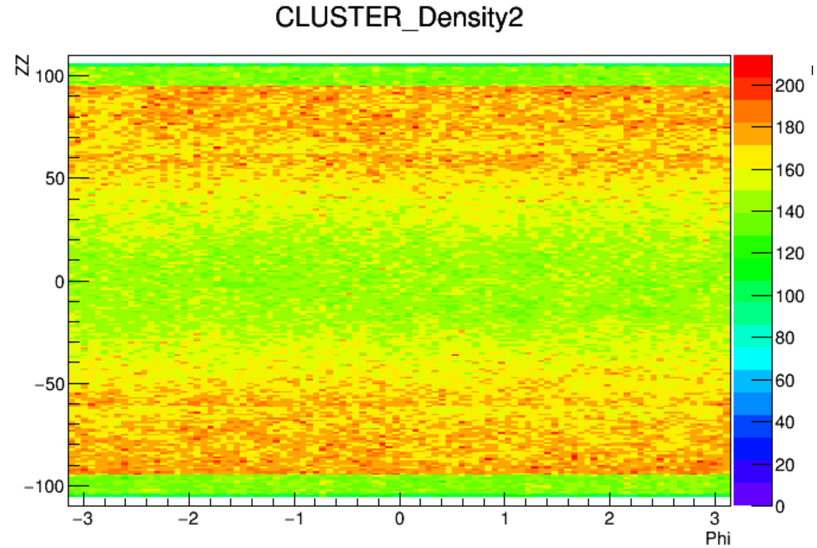


CLUSTER_ErrorPP [at layer 39]

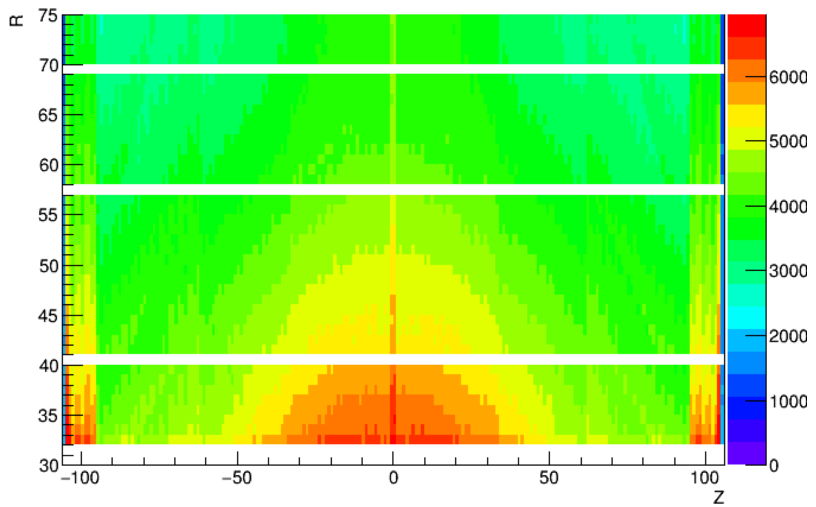


Clusterization



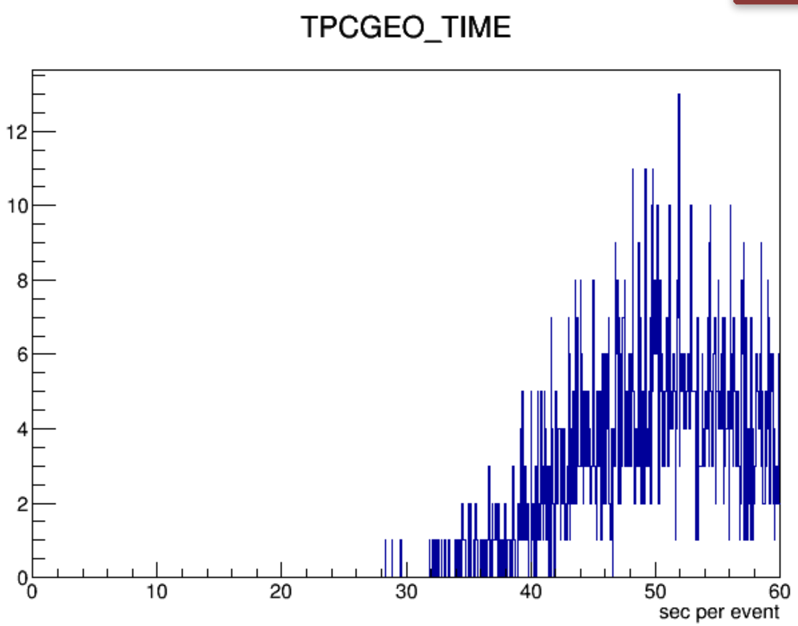


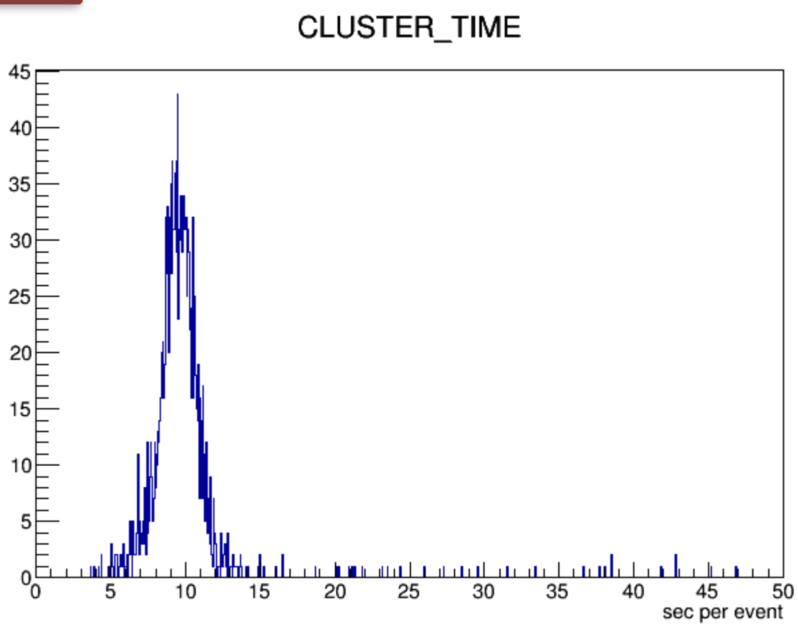
Hijing central



Timing of most intensive parts

Hijing central





From g4hits (dEdX) to free electrons and propagation to the endplate: less than a minute per central hijing event

From digits to clusters going through local maxima finder, weighted mean and standard deviation in rphi and z: ~10 seconds per central hijing event

and still little room for improvement: e.g. avoid change of coordinates

TPC simulation in a nutshell

1. Simulation of ionization energy loss in gas — Geant4
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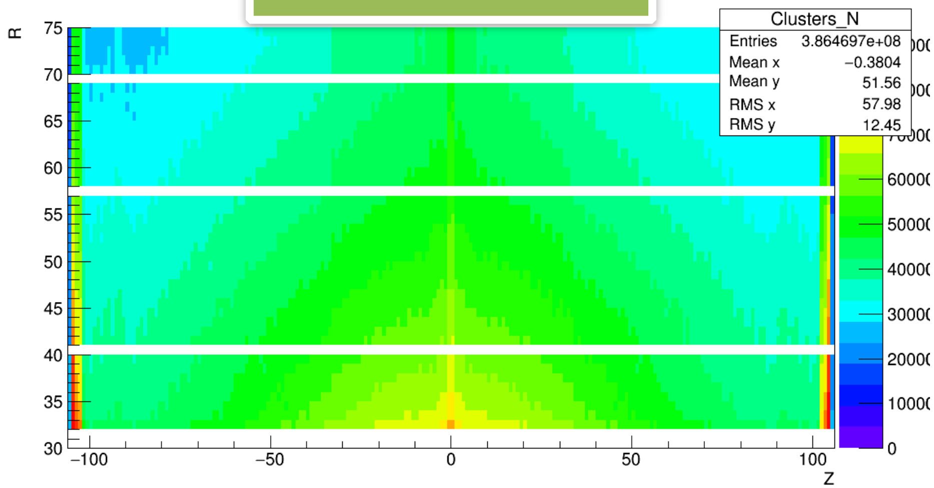
6. Time development of signal — parametrization
7. Digitization — parametrization
u8. Clusterization — basic algorithm, under further expansion

ADDITIONAL MATERIAL

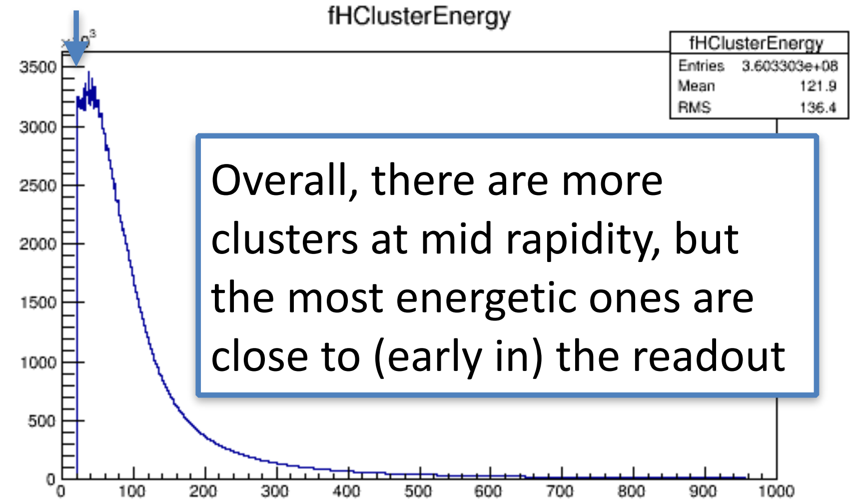
QA for clusterization

2000 central Hijing events

CLUSTER COUNTER

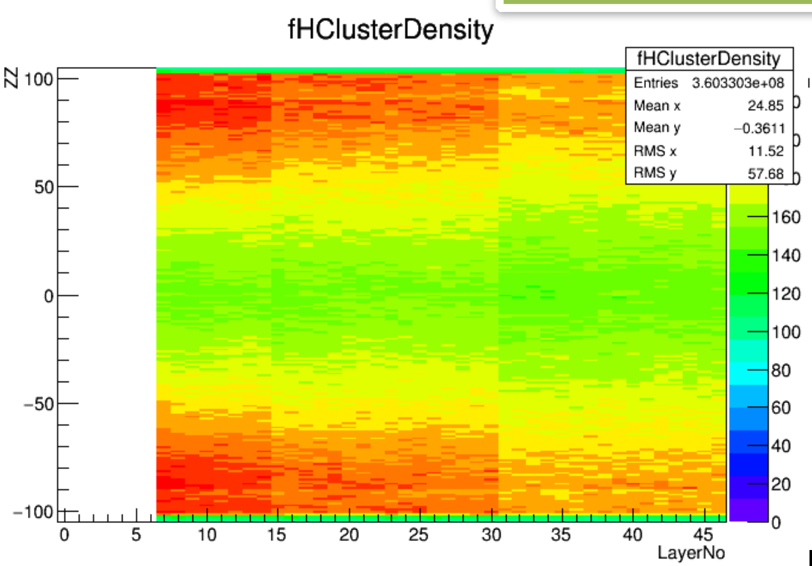


Cut at 20 adc

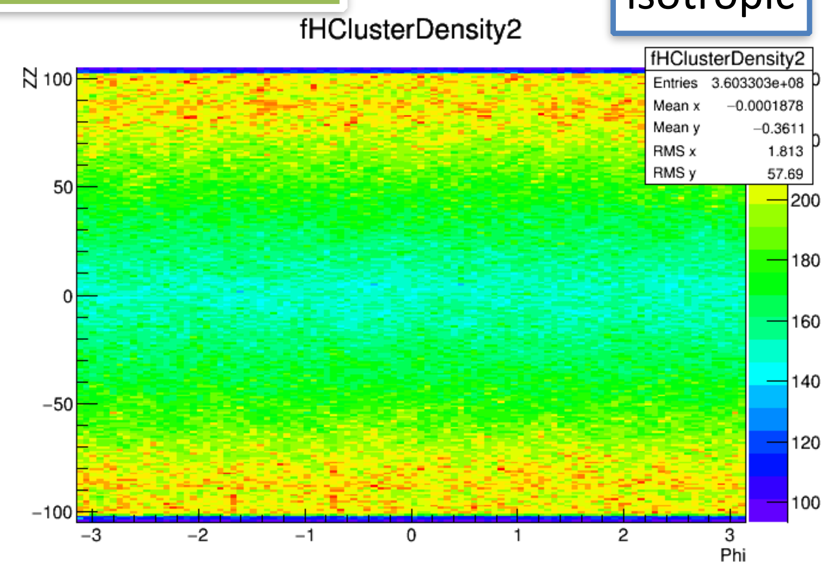


Overall, there are more clusters at mid rapidity, but the most energetic ones are close to (early in) the readout

CLUSTER DENSITY WEIGHTED BY ENERGY



isotropic



Formation of electron clouds due to ionization .

- Geant4 simulates the energy deposited in gas from particles in each point of the TPC volume
- Number of electrons produced are sampled from a poisson distribution using a constant number of electrons per kev.
- The electrons are then spread following a gaussian profile which sigma in the transverse and longitudinal direction is computed as:
  - sigmaT^2 = sigma0T^2 + DT^2 * L
  - sigmaL^2 = sigma0L^2 + DL^2 * L

DT and DL: diffusion coefficients in transverse and longitudinal direction

sigma0: intrinsic resolution

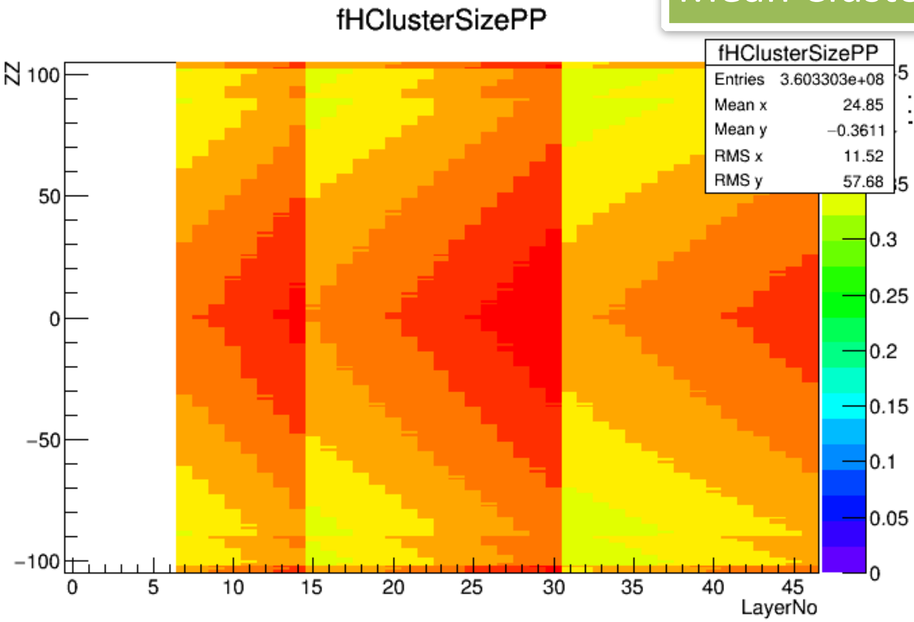
- Effect of residuals for space charge distortions are obtained from LUT and applied as displacement of the centroid

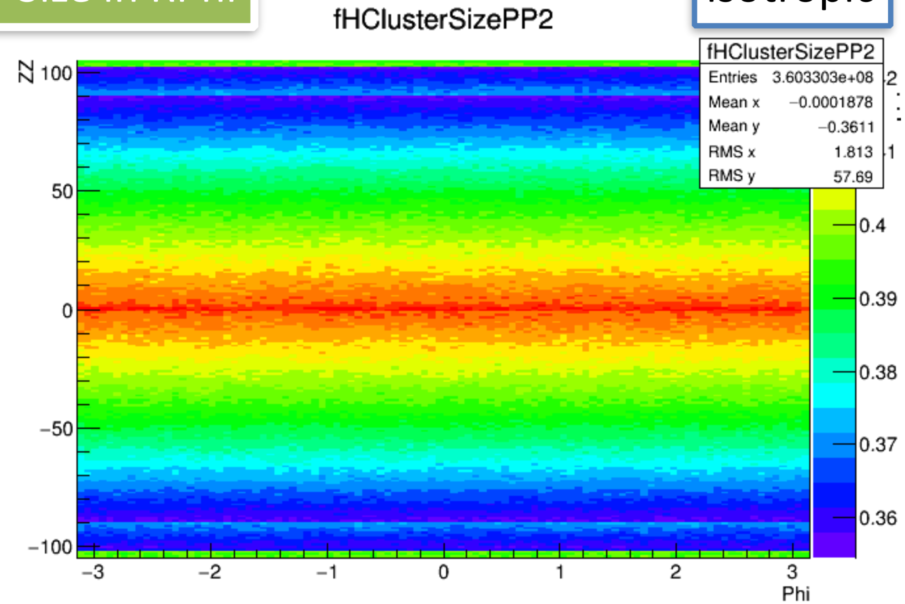
QA for clusterization

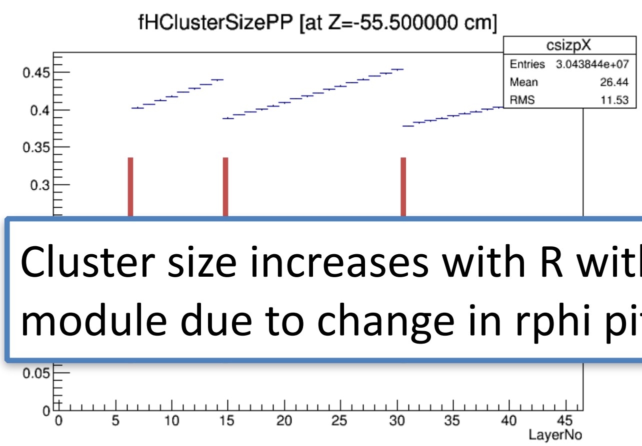
2000 central Hijing events

Mean Cluster Size in RPhi

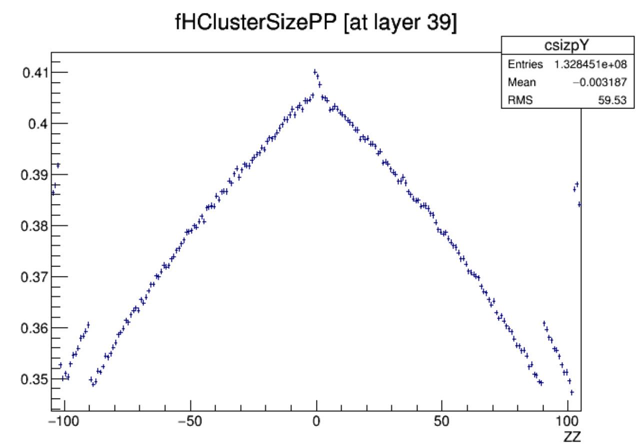
isotropic







Cluster size increases with R within a module due to change in rphi pitch.



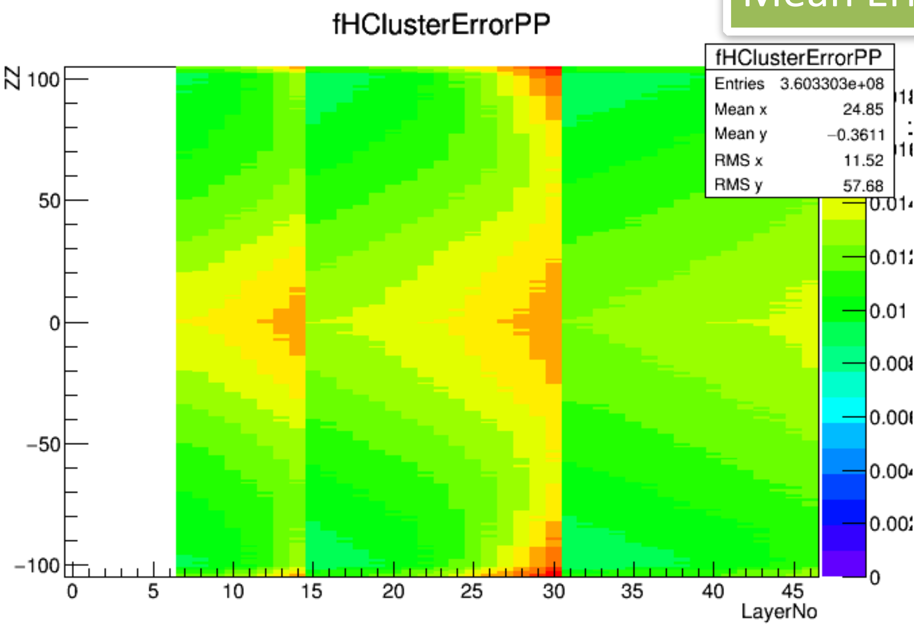
Size in Z is extracted from cells that pass threshold in integration window.

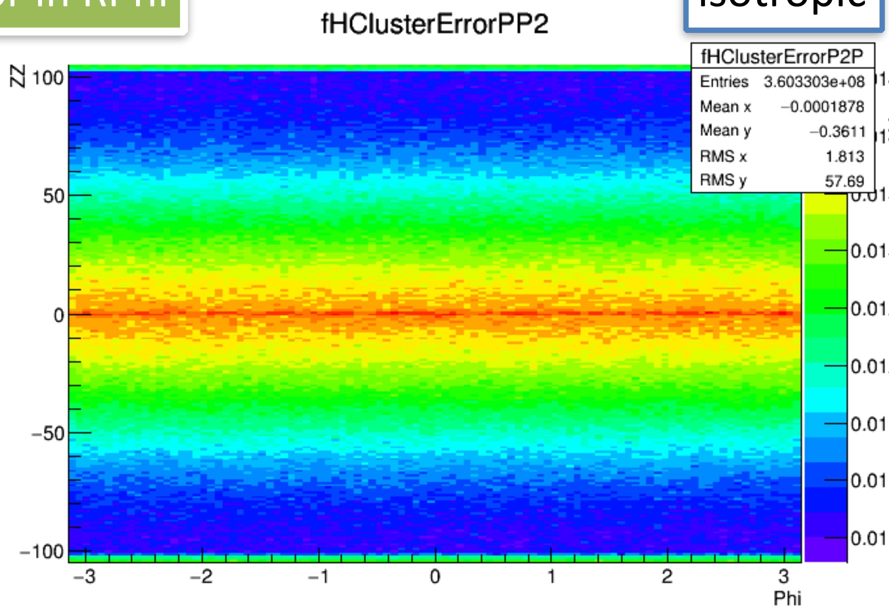
QA for clusterization

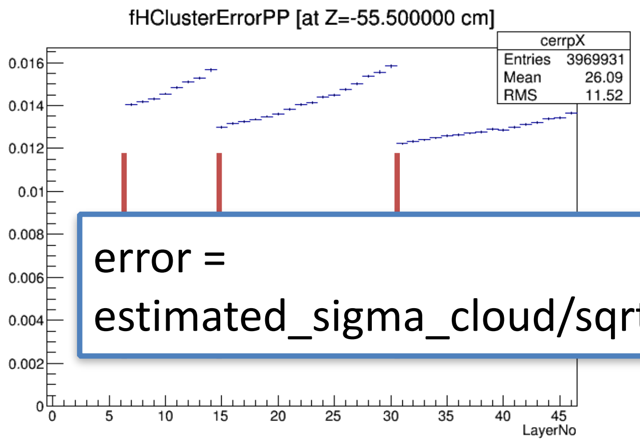
2000 central Hijing events

Mean Error in RPhi

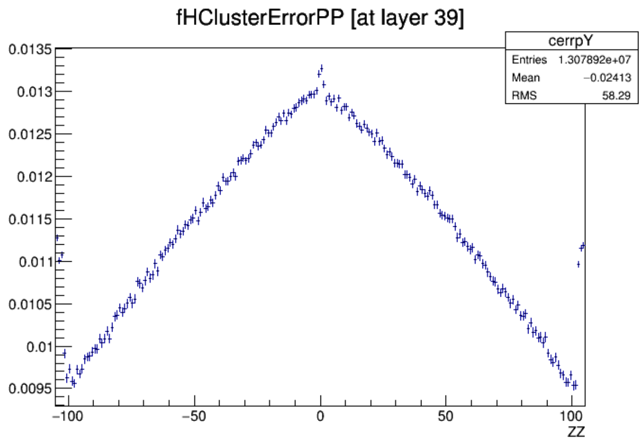
isotropic





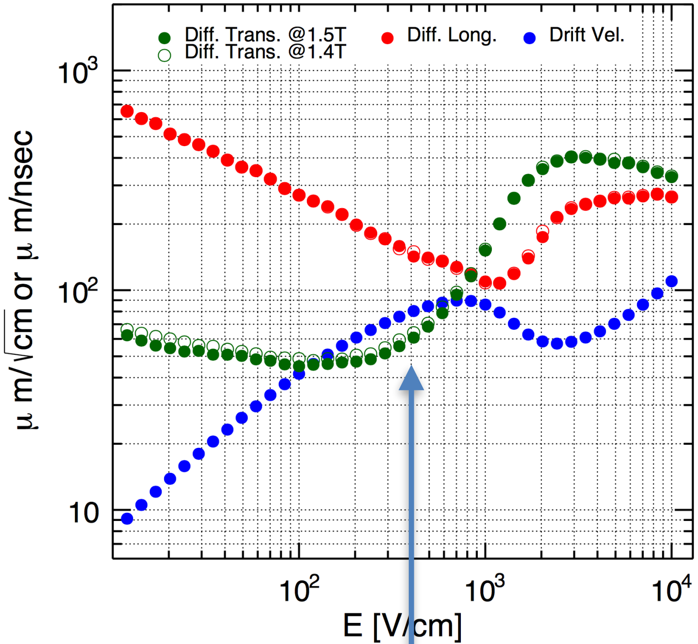


error = estimated_sigma_cloud/sqrt(signal)



Error are extracted from sigma of 2DGaussian distribution using catastrophic cancellation algorithm

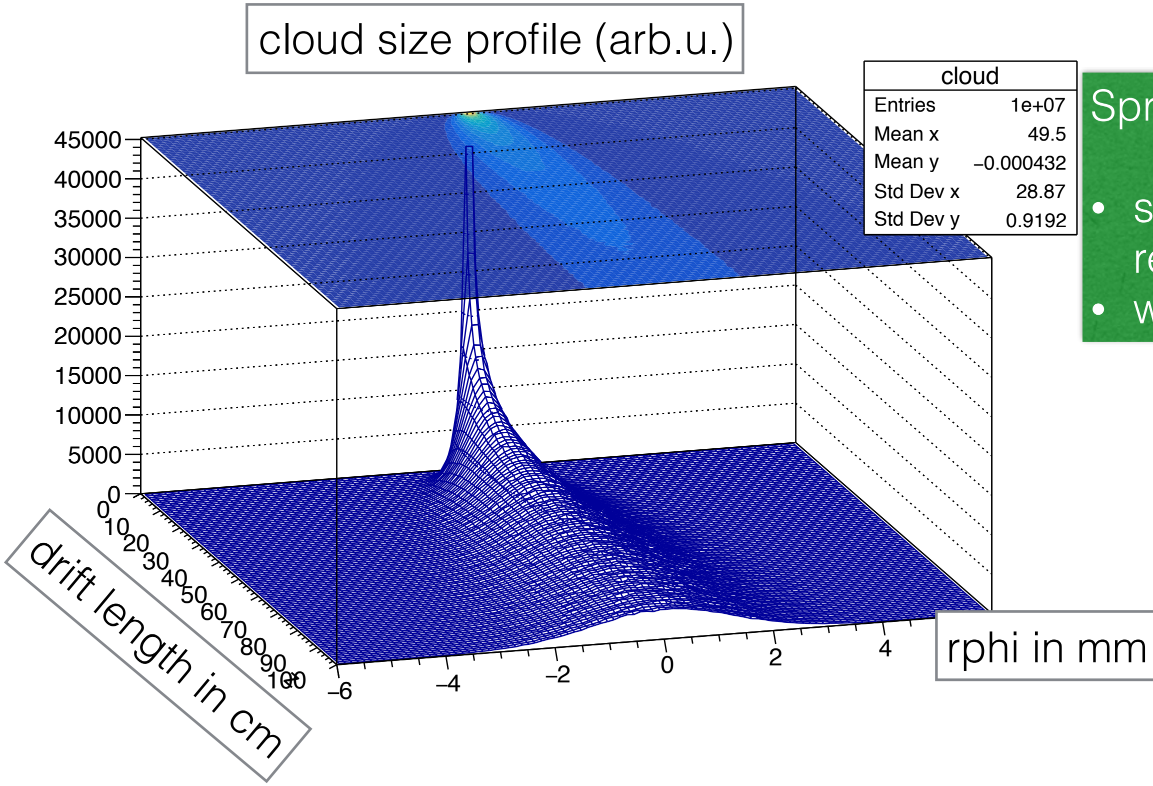
Currently gas under study



NeCF4 9010

Computation of gas properties based on finite elements simulation made by P. Garg (SBU)

Transverse diffusion coefficient 60 um/sqrt(cm)
Longitudinal diffusion coefficient 120 um/sqrt(cm)
Drift velocity 70 um/ns



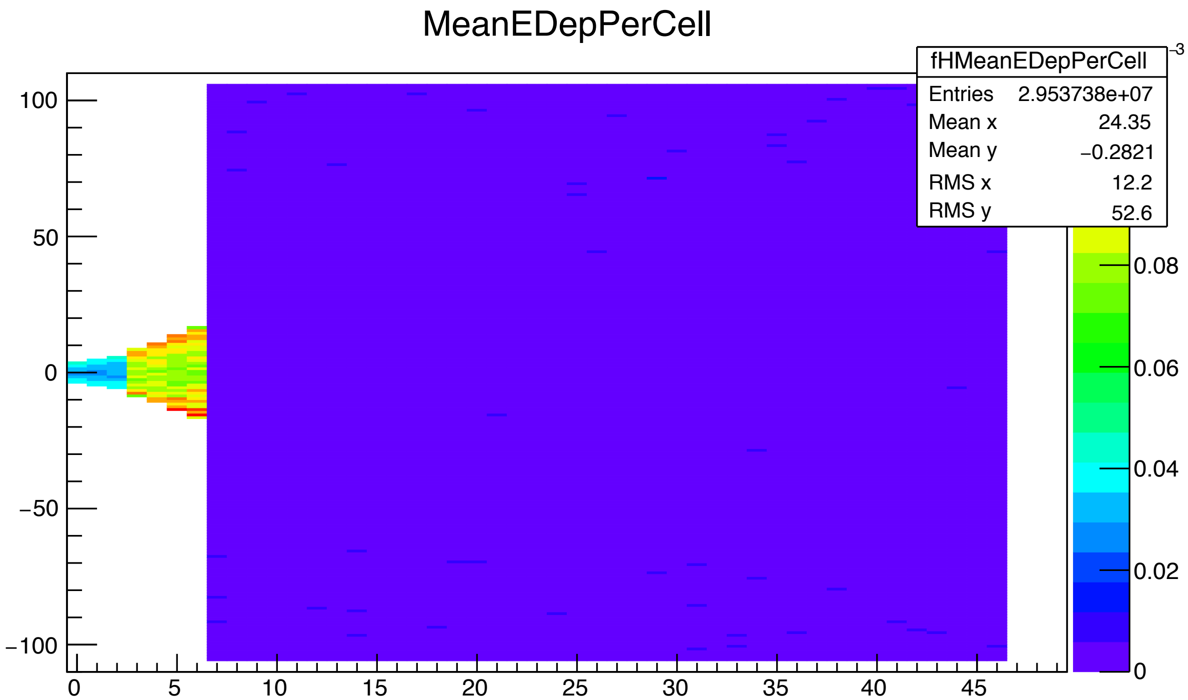
Spread over less than ~5 pads in rphi

- single pad for production close to readout plane
- wider spread as drift length increases

Simulation in PHG4CyllinderCellTPCReco

0.001	0.004	0.012	0.028	0.055	0.087	0.111	0.114	0.095	0.064	0.035	0.016	0.006	0.002	0.000
0.020	0.073	0.216	0.520	1.012	1.593	2.029	2.093	1.746	1.180	0.645	0.285	0.102	0.030	0.007
0.109	0.399	1.186	2.851	5.545	8.728	11.120	11.467	9.570	6.464	3.534	1.563	0.560	0.162	0.038
0.183	0.670	1.990	4.783	9.304	14.645	18.659	19.240	16.057	10.846	5.929	2.623	0.939	0.272	0.064
0.095	0.347	1.031	2.479	4.821	7.589	9.669	9.970	8.321	5.620	3.072	1.359	0.487	0.141	0.033
0.015	0.055	0.163	0.392	0.763	1.202	1.531	1.579	1.317	0.890	0.486	0.215	0.077	0.022	0.005
0.001	0.003	0.008	0.019	0.036	0.057	0.072	0.075	0.062	0.042	0.023	0.010	0.004	0.001	0.000

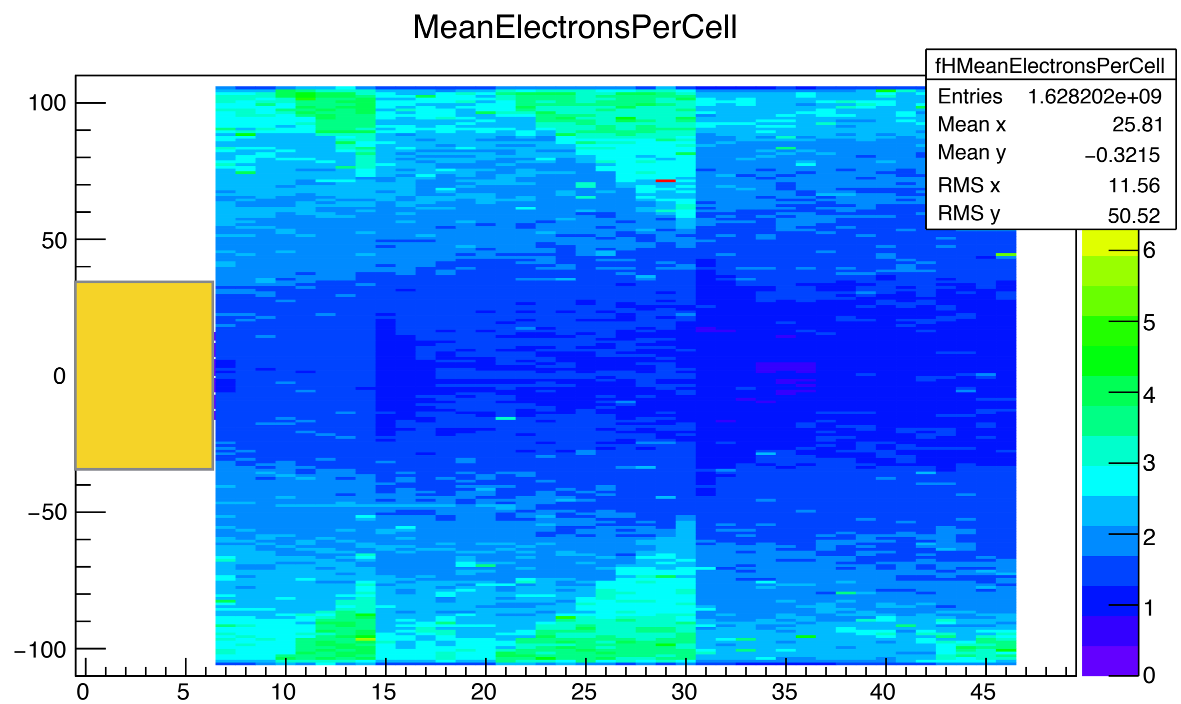
Fixed poissonian distribution to allow for more realistic spread



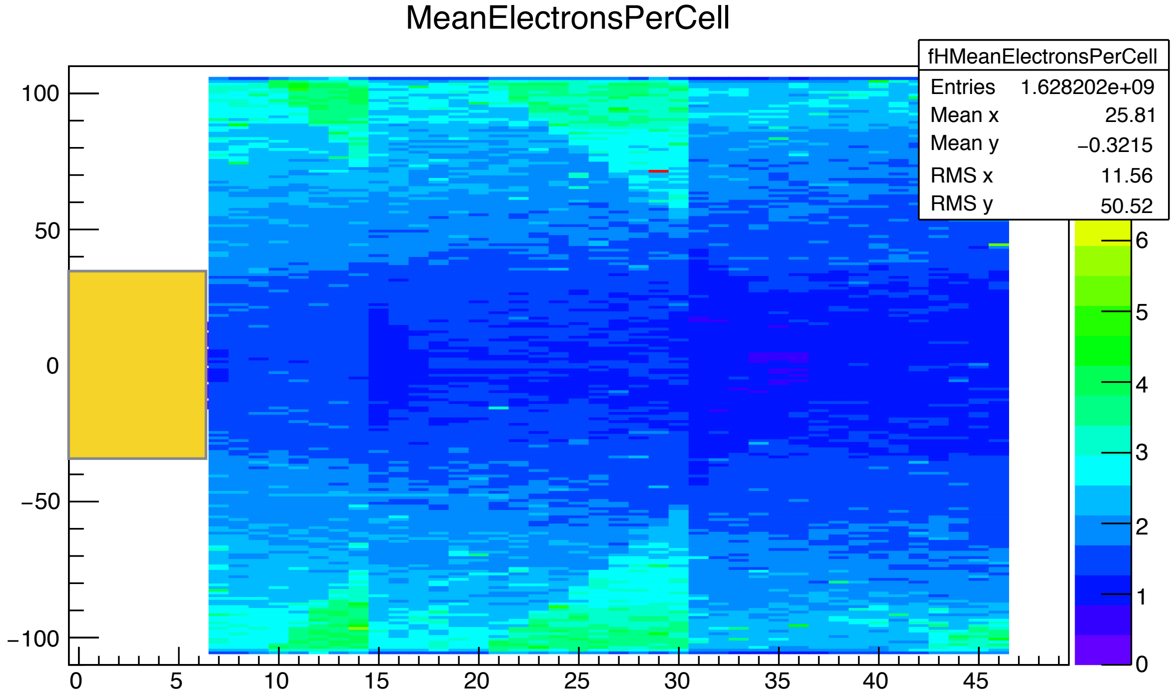
Mean Energy deposit from Central Hijing Events

Proportional to material budged

Binning:
1cm in Z
~1cm is Layer Width



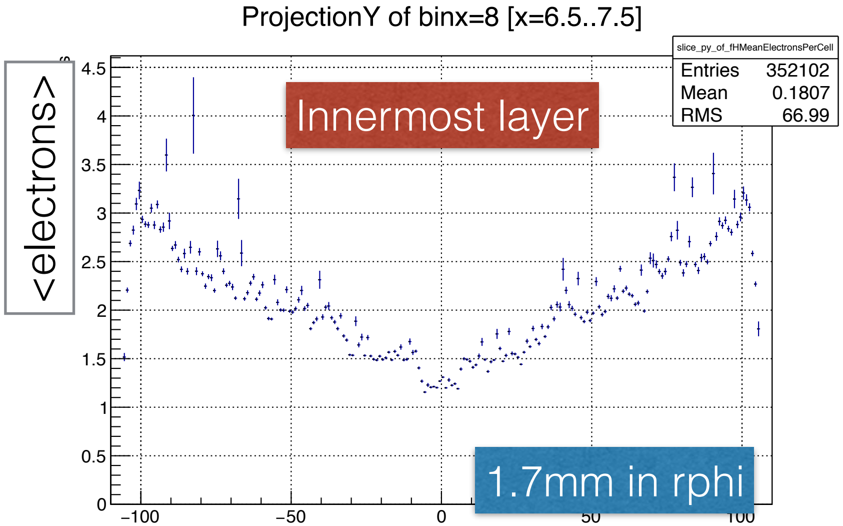
Mean Density of electrons from Central Hijing Events

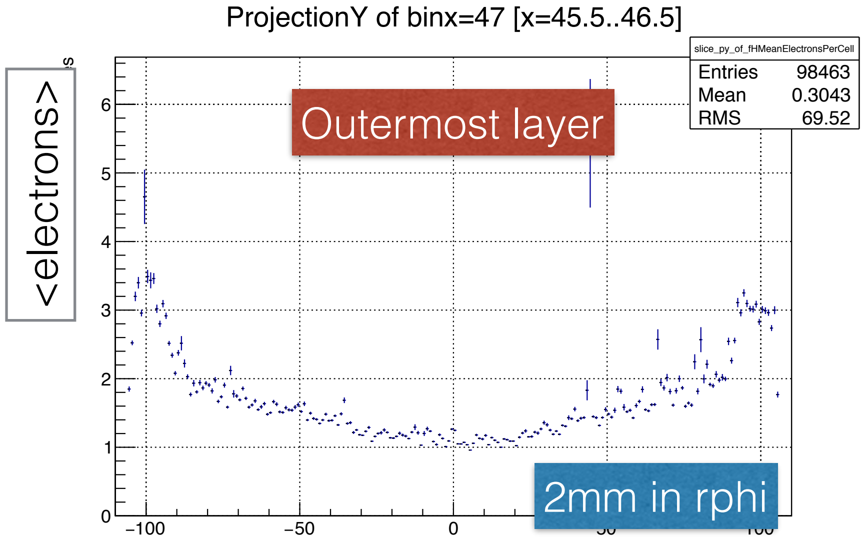


Mean Density of electrons from Central Hijing Events

Binning:
1cm in Z
~1cm is Layer Width

Run in pure pions and check then in R





Simulation of SpaceCharge Distortions

- The amount of ions present at every instance in the TPC generates an small electric field that causes distortions of the travel path of the electrons.
- The effect is non-negligible since there is a small but finite amount of ions that are fed back from the GEMs to the active volume that travel towards the central membrane.
- Space Charge distortions is computed as:
  - Charge density pile-up due to 50kHz collisional rate, average MB multiplicities, 3% ion back flow from GEMs.
  - Produced electric field is computed numerically by solving the poisson equation under cylindrical constrains.
  - Transport of electrons is computed via analytical Langevin equation where B field effects are also taken into account.

TPC Simulation Software

- Gas response simulation
  - Diffusion and spacecharge residuals are added in quadrature.
  - The electrons are spread into cells assuming a gaussian profile of the initial effective electrons over 3 sigma.

- Readout simulation
  - Clusters are formed from cells around local maxima
  - A integration window collects weighted centroid and (co)variances
  - Cluster size, centroid and error are handled back to Hough

Simulation of Diffusion

- Electrons produced by the tracks move to the end plate colliding with the gas molecules.
- The resulting charge density of the resulting cloud is:

$$\rho_{el} = \left(\left(\frac{1}{\sqrt{4\,\pi\,D_T\,t}}\right)^2 \mathrm{Exp}\left[-\frac{x^2+y^2}{4\,D_T\,t}\right]\right) \times \left(\frac{1}{\sqrt{4\,\pi\,D_L\,t}}\,\mathrm{Exp}\left[-\frac{(z-v_D\,t)}{4\,D_L\,t}\right]\right)$$

- where the DT and DL are the diffusion coefficients which depend on the gas choice and electric field applied. Additionally DT depends on the magnetic field as well:

$$D_T = \frac{1}{1+\omega^2\,\tau^2}\,D_T^0$$

Back-of-the-envelope Space Point Resolution

Space point resolution in TPC can be parametrised as:

$$\sigma^2 = \sigma_0^2 + \frac{D_T^2\, L}{n_{eff}} + \sigma_{SC}^2$$

Back-of-the-envelope Space Point Resolution

$$\sigma^2 = \sigma_0^2 + \frac{D_T^2 L}{n_{eff}} + \sigma_{SC}^2$$

Intrinsic resolution:
90um
(Bob Az. bench test)

Back-of-the-envelope Space Point Resolution

$$\sigma^2 = \sigma_0^2 + \frac{D_T^2 L}{n_{eff}} + \sigma_{SC}^2$$

Intrinsic resolution:
90um
(Bob Az. bench test)

SpaceCharge Residuals:
(Position Dependent)

avg better than 50 um

Back-of-the-envelope Space Point Resolution

$$\sigma^2 = \sigma_0^2 + \frac{D_T^2 L}{n_{eff}} + \sigma_{SC}^2$$

Intrinsic resolution:
60um
From TPC ILC measurements
90um achieved in bench test (Bob.A)

Diffusion term:
(Position Dependent)
DT = 70 um / sqrt(cm)
eff electrons ~ 28 (including effects from fluctuations in avalanche readout)
L = 100 cm

SpaceCharge Residuals:
(Position Dependent)

avg better than 50 um